AN ABSTRACT OF THE THESIS OF

Karen K. Austin for the degree of Master of Science in Wildlife Science presented on June 18, 1993

Title: Habitat Use and Home Range Size of Breeding Northern Goshawks in the Southern Cascades.

Abstract approved:

William C. McComb

I investigated habitat use and home range size of northern goshawks in the southern Cascades, in the Shasta-Trinity and Klamath National Forests of northern California. My objectives were to 1) estimate the average home range and 2) describe the use of habitats within home ranges by breeding goshawks.

Ten goshawks (5 males, 5 females) were trapped, radio-transmitters attached, and tracked for approximately 50 days during the breeding season in 1988 and 1989. A mean of 33 data points per bird (range = 27-43). produced home range estimates (100% minimum convex polygon method) of 2,425 ha (range = 1083-3902 ha) for 5 males and 3,774 ha (range = 2007-6908 ha) for 5 females.

Vegetation plots were sampled at 20 locations determined by radio-tracking (used) and 20 locations randomly identified (available) in each of 9 goshawk home ranges. Two variables were sampled within 30-m radius habitat plots, average dbh and canopy closure. These

variables were combined to classify the plot into 1 of 5 classes.

Goshawks used habitats within their home ranges non-randomly. Analyses of individual goshawk habitat selection were not conclusive, but trends in individual habitat selection was used to examine pooled analysis results.

Goshawks avoided open habitats (meadows, seedling and sapling stands) and individual trends supported pooled analysis results. Goshawks did not avoid or select pole habitat stands, and individual trends supported these results. Goshawks avoided open-canopied, small sawtimber and mature stands (26-52+ cm dbh, canopy closure < 40%), but trends in individual goshawk selection were inconsistent. Stands of closed-canopied, small sawtimber (26-51 cm dbh, canopy closure $\geq$ 40%), the most abundant habitat type within goshawk home ranges was not selected or avoided by goshawks, and individual trends agree with pooled results. Goshawks selected closed-canopied stands of mature and old-growth habitat ($\geq$ 52 cm dbh, canopy closure $\geq$ 40%), and trends in individual goshawk selection generally agreed with pooled results.

Management recommendations are not meant to be extrapolated beyond the limitations of my study, but in the absence of other information this data can be used in developing interim recommendations and can help focus future research efforts.

The area considered for management of habitat for breeding goshawks should include a minimum of 4,765 contiguous hectares (11,774 acres), within which habitats should be managed for goshawk foraging, resting, nesting, and raising young. Habitats managed for goshawks should include a minimum of 20% of each area in closed-canopied mature and old-growth forest ($\geq$ 52 cm or $\geq$ 21" dbh, canopy closure $\geq$ 40%), and a minimum of 40% in closed-canopied small sawtimber forest (26-51 cm, or 11-21" dbh, $\geq$ 40% canopy closure). No more than 10% of the management area should be maintained in the seedling/sapling/grass-forb habitats and unforested condition.

# Habitat Use and Home Range Size of Breeding Northern Goshawks in the Southern Cascades.

by

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## INTRODUCTION

Goshawks (Accipiter gentilis) inhabit forested areas throughout the northern hemisphere. Goshawks breed from timberline in the arctic south into Mexico and are widely distributed in Europe and Asia (Johnsgard 1990). In northern California, Oregon, and Washington goshawks nest in mountainous, coniferous forests (Reynolds and Wight 1978, Bloom 1981, Johnsgard 1990).

There is a growing concern that timber harvest is causing declines of goshawk populations (Reynolds 1983, Bloom et al. 1986, Fowler 1988, Crocker-Bedford 1990, Reynolds et al. 1991). Mature and old-growth forest are often selected by goshawks for nesting (Reynolds et al. 1982, Saunders 1982, Moore and Henny 1983, Hall 1984, Bloom et al. 1986) and have also been the preferred forests for harvesting timber. There has been little research or monitoring information with which to adequately assess the status of goshawk populations in the Pacific northwest (Fowler 1988, Reynolds et al. 1991).

In response to a petition to list goshawks in the western United States as threatened (Babbitt et al. 1991) the U.S. Fish and Wildlife Service included western populations of the goshawk on the list of category 2 candidate species (50 CFR 58810). This status means that existing

> "information ... indicates that proposing to list as endangered or threatened is possibly appropriate, but ... conclusive data on biological vulnerability and threat are not currently available to support [listing]" (50 CFR 58804).

Goshawk research in the Pacific Northwest has been limited mainly to describing nesting habitat for this large, forest raptor (Reynolds et al. 1982, Saunders 1982, Moore and Henny 1983, Hall 1984, USDA Forest Service 1984, Bloom et al. 1986, Fowler 1988). In the Pacific Northwest this species often is described as nesting in closed-canopied, mature and old-growth coniferous forests (Saunders 1982, Reynolds et al. 1982, Moore and Henny 1983, Hall 1984, Bloom et al. 1986, Fowler 1988). This species is considered by some to be a habitat generalist because it is found in a wide range of forest communities in North America (Johnsgard 1990, Reynolds et al. 1991), but information regarding the goshawk's use of habitats of different seral stages or stand structures for foraging or resting is uncommon (Fischer and Murphy 1986, Widen 1989, Hargis et al., In press).

In Region 5 of the U.S. Forest Service (California) the goshawk is considered a sensitive species, an agency classification which gives it special consideration during land planning decisions and gives priority to identification of habitat associations and creation of land management guidelines. The current direction for managing goshawk habitat in Region 5 is to maintain 1 goshawk nesting territory per 46.6 $km^2$ (18 $miles^2$) (USDA Forest Service 1984). Each reserved nesting territory is to include a 10-ha (25-acre) buffer of suitable nesting habitat around the primary nest and a second 10-ha buffer within 0.80 km (0.50 mile) located around an alternate nest (USDA Forest Service 1984).

Information on goshawk habitat use outside of the nest stand is important to land managers responsible for maintaining populations. Land management activities (e.g. timber harvest, road development, campground development) often occur within goshawk home ranges which could adversely impact the suitability of habitats for breeding goshawks.

# OBJECTIVES

I investigated habitat use and home range size of northern goshawks in the southern Cascades within the Shasta-Trinity and Klamath National Forests of northern California. My objectives were to 1) estimate the average home range and 2) describe the use of habitats within home ranges by breeding goshawks.

# STUDY AREA

My study area was in the southern Cascade mountains of northern California. The northeast and southeast portions of the Shasta-Trinity and the Klamath National Forests defined the study area. The area is flat or gently sloping terrain bisected by a volcanic east-west ridge connecting Mt. Shasta and Medicine Lake. Elevation ranges from approximately 1,100 m (3,608 ft) to 2,200 m (7,216 ft). The area is diverse with 5 forest cover types dominating the landscape (Eyre 1980). These cover types are Sierra Nevada mixed-conifer, Pacific ponderosa pine (Pinus ponderosa), lodgepole pine (Pinus contorta), red fir (Abies magnifica), and white fir (Abies concolor) (Eyre 1980). Forests are periodically interrupted by dry meadows (> 40 ha), high elevation brushfields and lava flows. Few natural, perennial water sources exist with the exception of the McCloud River and Medicine Lake.

This area is fragmented in part caused by a 100-year history of timber harvest (Hanft 1971). To illustrate, many quarter-townships (2,333 ha, 9 square miles) of the northern half of the McCloud Ranger District just meet or do not currently meet the 50-11-40 landscape standard for the northern spotted owl (Strix occidentalis caurina) (Thomas et al. 1990, Miller pers. comm.). My study area is composed of ≥ 50% of the forested land in young or sparsely forested habitats (stands defined by trees $\leq$ 11" average dbh and/or average canopy closure < 40%).

The reproductive success and productivity of successful and active nests are lower than documented for other study areas (Appendix 1 and 2). Yearly numbers of breeding goshawks located during U.S. Forest Service wildlife surveys seem to have been relatively constant over the last 8 years (1982-1990; unpublished data). Although reproductive data suggest that reproduction of goshawks between 1987-1990 is lower than for other study areas (Appendix 1 and 2) more information is needed for this goshawk population to determine if these reproductive values indicate whether the population is declining or stable (Steenhof 1987).

# METHODS

## Locating goshawk nests

Crews surveyed for active goshawk nests from mid-May to early June of 1988 and 1989. Active nests were located by looking and listening for signs of goshawk activity in areas with previously documented nesting activity, recent goshawk sightings, or areas of suitable nesting habitat. Suitable nesting habitat was defined for the study area by Saunders (1982). Goshawks that were included in this study were actively nesting (live chicks in the nest) on National Forest land. Selected nests were scattered throughout the study area and fell within the major forest cover types (Eyre 1980) found in the study area.

## Radio-tracking data collection

My crews and I trapped 16 adult goshawks and fitted these birds with radio-transmitters (6 females, and 4 males in 1988; Appendix 3) (3 females, 3 males in 1989; Appendix 4). Goshawks were trapped after chicks were $\geq$ 2 weeks in age and in dry weather to minimize stress on the chicks.

Trapping was conducted using a decoy, non-releasable great horned owl (*Bubo virginianus*) and break-away mist-net (Hamerstrom 1963) in the vicinity of the nest. Radio-transmitters were attached with 6.35-mm teflon ribbon in a backpack position (Kenward 1987) and goshawks were banded with U.S. Fish and Wildlife Service metal tarsus bands and plastic tarsus bands with numbers which can be read up to 50 meters.

To reduce navigation and mapping errors numbered stakes and plastic colored flagging were placed along roadsides at recorded intervals of 322 m (0.2 miles) within a 2.4-km radius of radio-marked goshawk nests. U.S. Forest Service 1:15,840 scale (6.3 cm/km, or 4 inches/mile) topographic maps were corrected using aerial photographs to include accurate road locations and to identify stake locations. Corrected maps were used for navigation in the field to identify observer location coordinates and as data recording forms for radio-tracking bearings and locations.

Radio-tracking began the first week in July and continued until the end of August in 1988 when fledglings began to disperse (approximately 50 days of a post-hatching breeding season of 90 days). In 1989 the radio-tracking period was discontinued in mid-August when problems with radio-transmitter signals prompted a change in study objectives.

The objective of radio-tracking was to collect a random selection of goshawk locations which represented the normal, daily activities and habitats used by the individuals during the breeding season. I assumed that each radio-tracking location represented a resting or foraging location for that goshawk.

Goshawks were tracked in a random order each day and the time of day that radio-tracking locations were collected was random.

The goal was to collect a representative sample of locations randomly throughout the breeding season to approximate independence (White and Garrott 1990: 148). To meet this goal in 1988, my crews and I planned to collect 1 location for each goshawk randomly each day. This plan often was not realized because of difficulties in obtaining radio-tracking locations on these frequently moving raptors. Same-day radio-tracking locations often were collected to increase the sample of locations. The first location for each bird each day was collected randomly but the subsequent locations were not randomly collected. Of the total radio-tracking locations collected for the 8 goshawks considered in 1988, 69% of these locations were collected on different days. Of the 31% of same-day locations 54% were collected $\geq$ 2 hours apart.

The goal in 1989 was to assign 2 goshawks randomly to each observer and collect consecutive locations for each goshawk for approximately half of each day. This purpose of this change in 1988 was to decrease the time traveling between goshawk home ranges each day and to allow more time to collect a larger number of radio-tracking locations for each goshawk than the previous year. Of the total radio-tracking locations collected for the 2 goshawks considered in 1989, 23% of these locations were collected on different days. Of this 77% of same-day locations, 16% were collected $\geq$ 2 hours apart.

A visual observation of a goshawk or a "box signal" (a signal obtained without antenna or cord was estimated to be $\leq$ 30 m from the radio-tagged goshawk) was attempted for 1 goshawk radio-tracking location by each observer each day. Nine percent of the total radio-tracking locations collected were "box signal" or visual locations.

Radio-tracking polygons

Signal bearings were determined using the loudest signal method (Springer 1979). Radio-tracking polygons were plotted using the "ad hoc" method (Nams and Boutin 1991) or by plotting the intersection of > 3 or more signal bearings (Mech 1983: 77) taken within a 15-minute period. Bearings were plotted on maps immediately after the azimuth was determined.

I assumed that the smaller the size of the radio-tracking polygon the greater the accuracy of the location (Kenward 1987). In the case of polygons $\geq$ 1 ha (2.5 acres) additional bearings were attempted immediately to decrease the size of the radio-tracking polygon (Kenward 1987) or a second polygon was attempted. Radio-tracking polygons estimated at > 1 ha were not considered accurate enough for habitat analysis (Solis and Gutierrez 1990) and polygons estimated at > 8 ha were not considered accurate enough for home range analysis. Locations of goshawks were estimated at the geometric center of radio-tracking polygons (Mech 1983) and this location was recorded on a data sheet as a Universal Transverse Meridian (UTM) coordinate (10-m grid).

In order to reduce bearing error and minimize the size of the radio-tracking polygon, I attempted to collect bearings within an estimated 805 m (1/2 mile) of the goshawk and to obtain bearings that formed close to equal-sided triangulations.

Home range analysis

Data from 10 goshawks with $\geq$ 20 radio-tracking locations were included in home range analyses (4 males, 4 females in 1988; Appendix 3)(1 male, 1 female in 1989; Appendix 4). All 10 goshawks fledged young and at least 1 juvenile was known to be alive during radio-tracking data collection. A mean of 33 locations per bird were collected for the 10 individuals used in the analyses (range: 27-43) (Appendices 3 and 4).

Information for the male and female of 1 pair was analyzed. I assumed that the home range use of each individual was independent of other goshawks including that of the pair. Overlap between adjacent pairs was not analyzed.

Home range size was described with the minimum convex polygon (MCP) method (Mohr 1947) using the program Telem88 (Coleman and Jones 1988). The 100% MCP home range was estimated for each goshawk and a mean for male and female goshawks calculated.

I hypothesized that the average female and male goshawk 100% MCP home range size were equal. I tested this hypothesis using a univariate, nonparametric Kruskal-Wallis test (Devore and Peck 1986: 607).

Habitat selection analysis

Of the 16 goshawks with radio-transmitters, information from 9 birds was used for habitat analysis. These were 9 of the 10 goshawks analyzed for home range use.

To test the null hypothesis, that goshawks are selecting foraging and resting locations in the proportion that they occur within home ranges, a sample of goshawk locations and random locations were identified within each of 9 home ranges.

A sample of 20 radio-tracking locations referred to as used were selected from the total locations for each goshawk. Criteria for locations used in habitat selection analyses was different-day locations, radio-tracking polygons estimated at ≤ 1 ha, visual observations, and locations collected through the time period in which each goshawk was tracked.

A random sample of 20 locations from within the home range (100% MCP) referred to as available were identified for each goshawk. Coordinates (UTM, 10-m grid) for random locations were chosen using a random numbers program on a hand-held calculator for each coordinate digit within the range of values falling within each home range.

Habitat plots placed at the center of each radio-tracking and random locations were sampled and habitats classified. Differences in the proportion of locations among various habitats for all goshawks (pooled data) were investigated. My research focused on stand-level selection (third-order selection) within the home range (Johnson 1980). I estimated the habitat use and availability for each animal independently (Design 3; Thomas and Taylor 1990) rather than comparing an area of habitat availability for all animals jointly. I assumed that the habitat use of each goshawk was independent of other goshawks.

Habitat sampling

Habitat sampling was conducted within a 30-meter radius circular plot (0.28-ha) with 1 plot located at the center of each used location and at the coordinate for each available location. Locations of each habitat were identified using a map and compass. I assumed that mapping or orienteering error did not affect data results.

Variables collected in each plot included the average tree size class (average diameter breast height [dbh]) of the overstory trees and average canopy closure (%) (Table 1). Variables were visually estimated during data collection. A spherical densiometer and diameter tape were used regularly during the field work by all data collectors for calibration.

The result of habitat analysis was creation of a categorical variable called habitats, a structural description composed of average canopy closure (%) and average size class of the stand (avg. dbh). Five habitat classes were used for the habitat selection analyses (Table 1). This variable was based on a forest structural classification system used by the U.S. Forest Service Region 5 (Appendix 5) (USDA Forest Service 1987). I minimized the number of habitat classes for statistical analyses to ensure an average expected frequency in each category of $\geq$ 6 (Marcum and Loftsgaarden 1980).

Changes in the forest structure such as a clear-cut edges sometimes bisected plot boundaries. Where this occurred, I assumed that the goshawk was perched in the half of the plot with perch trees or with the highest density of perch trees and the timber type of that half was assigned as the value for the plot. I assumed that this bias would not affect habitat selection results.

Statistical analysis

Categorical habitat data were used to test the hypothesis that goshawks used habitats within home ranges randomly or that goshawk locations fell within habitats in proportion to availability. The objective was to determine

Table 1. Habitat classifications used in analysis of breeding goshawk habitat selection, southern Cascades, California, 1988 and 1989.

| Habitats [a] | Size class (dbh [b]) | Canopy closure (%)[c] |
|---|---|---|
| Seedling/ sapling/ grass-forb. | 0-11 | 0-100 |
| Pole | 12-25 | 10-100 |
| Open-small sawtimber/ mature | 26-52+ | 10-39 |
| Closed-small sawtimber | 26-51 | $\geq$ 40 |
| Closed-mature/ old-growth [d] | $\geq$ 52 | $\geq$ 40 |

a Forest structural stages were pooled to create 5 habitats (Appendix 5).
b dbh = diameter at breast height (cm)
c Average canopy closure is measured from shrub height (approximately 2 m) and higher. This measure was averaged over a 30-meter radius plot (see methods section).
d Old-growth forest is included in the description of the oldest habitat but is not found within most of my study area.

whether goshawks were selecting or avoiding available habitats.

Values for use and availability for all goshawks within each habitat were pooled (Marcum and Loftsgarden 1980) because of small sample size of radio-tracking locations for each goshawk. The chi-squared test of homogeneity was used to test for differences in proportions of available versus used location frequencies among habitats ($n$ = 5) for all goshawks (pooled data, $n$ = 9) (Marcum and Loftsgaarden 1980).

The next analysis step was a series of simultaneous confidence tests (Bonferonni $z$-statistic; Devore and Peck 1986: 578) to identify whether goshawks (pooled) were selecting or avoiding any of the 5 habitats (Marcum and Loftsgaarden 1980).

A similar set of statistical tests were conducted for each goshawk individually. I used a chi-squared test of homogeneity to determine differences in used versus available habitats by each goshawk. The difference between use and availability among individual goshawks and habitats was calculated (Thomas and Taylor 1990) and used as non-statistical trends to strengthen pooled analyses. Simultaneous confidence intervals (Marcuum and Loftsgaarden 1980) were not calculated because of the small sample size of locations for each goshawk. Statistical analyses were performed on SAS (1987) and in BASIC (Chi-squared analysis, Brower et al. 1989: 207) with $P < 0.10$.

Location error

I did not consider bearing error when determining goshawk radio-tracking locations. Because of bearing error the polygon is not exact but is an area of error (Springer 1979). This error describes an area of probability of an animal occurring within this area (Springer 1979, Nams and Boutin 1991). The larger the area in relation to the average habitat patch the greater is the chance of overlapping more than 1 habitat, which creates a bias (White and Garrott 1986, Nams 1989). The observed habitat use is biased away from actual habitat use and towards the proportion of habitats available (White and Garrott 1986, Nams 1989). This bias reduces the power of statistical tests for habitat selection (White and Garrott 1986), and distorts measures of habitat selection (Nams 1989). The solution of disregarding all telemetry locations whose areas cover more than 1 habitat has been suggested, although this can further reduce sample sizes and the power of statistical tests to identify habitat selection (Nams 1989).

My radio-tracking data and habitat sampling data were collected before I analyzed the effect of radio-tracking bearing error on location estimates.

However, Kenward (1987) and Nams (1989) argued that radio-tracking error in habitat analysis can be examined at the system precision level, and knowledge of the confidence associated with each location is not essential to habitat selection analyses. It was more practical and equally as effective for habitat selection analysis to use a traditional statistical approach rather than a Bayesean approach to assess habitat selection (Nams 1989).

# RESULTS

## Autocorrelation of locations

The time of day that my radio-tracking locations were collected was random (between 0700 and 1900). Random collection of location days throughout the radio-tracking time period was accomplished, but because some locations were same-day locations the data are likely autocorrelated. Sixty-nine percent of the 1988 radio-tracking data used for home range analysis were collected on different days (approximately randomly), but only 23% of the 1989 data were collected on different days.

## Home range size

The average 100% MCP home range estimate for 10 goshawks was 3,100 ha (Table 2). The 100% MCP home ranges were similar for males (2,425 ha) and females (3,774 ha) ($P = 0.46$, Table 2). The home range overlap for 1 pair of goshawks was 38% of the female home range.

## Habitat selection

Goshawks used habitats within their home ranges non-randomly (Chi-squared = 25.02, 4 df, $P < 0.001$) (Table 3). Goshawks (pooled data) avoided the seedling/sapling/grass-forb habitat and the open-small sawtimber/mature habitat, and selected closed-mature/old-growth habitat (Figure 1, Table 3).

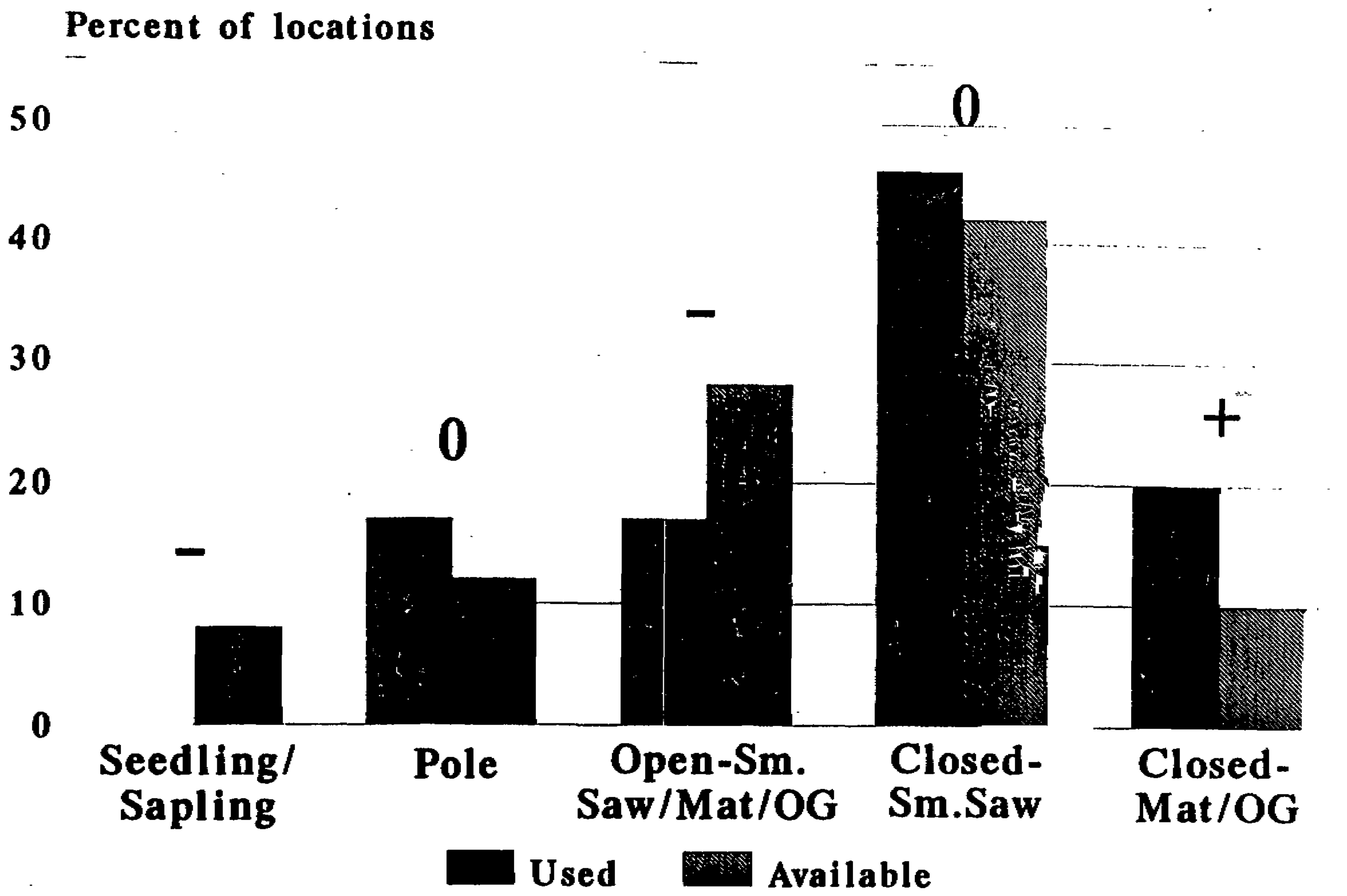
Table 2. Average 100% Minimum Convex Polygon breeding home range (hectares) for male and female goshawks, southern Cascades, California, 1988 and 1989.

| Goshawk | $\underline{n}$ | Mean | SE | Range |
|---|---|---|---|---|
| Male | 5 | 2,425 [a] | 624 | 1083-3902 |
| Female | 5 | 3,774 [a] | 836 | 2007-6908 |
| Total | 10 | 3,100 | | |

a No difference between average male and female home ranges; Kruskal-Wallis non-parametric test ($\underline{P}$ = 0.46).

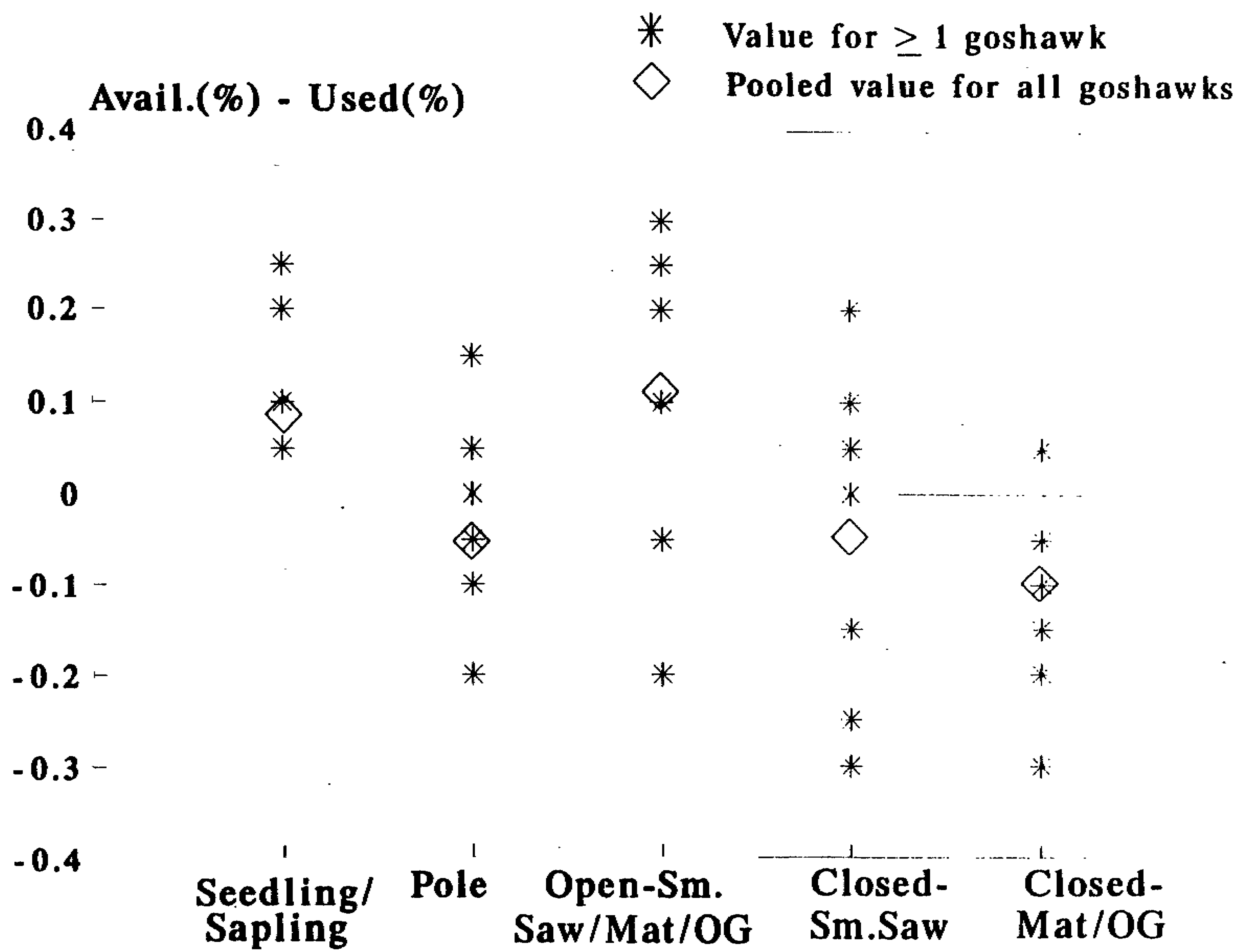
b Mean sample size of locations per goshawk which were used to generate these MCP values is 33 (range 27-43).

Figure 1. Analysis of breeding goshawk habitat selection, southern Cascades, California, 1988 - 1989. Bonferroni simultaneous confidence test (overall confidence 95%, and individual confidence 99%) for 5 habitats (pooled data, $n$ = 9 goshawks). Habitats are seedling/sapling/grass-forb, pole, open-small sawtimber/mature/old-growth, closed-small sawtimber, and closed-mature/old-growth and are defined in Table 1. A "0" value above bars indicates that no difference in frequency of use versus availability occurred for the habitat; a "-" value indicates that the frequency of use of the habitat was less than available and avoidance of this habitat was found; a "+" value that the frequency of goshawk pooled use of the habitat was greater than available thus selection was found.



Percent of locations
50
40
30
20
10
0
−
0
−
0
+
Seedling/ Sapling
Pole
Open-Sm. Saw/Mat/OG
Closed-Sm.Saw
Closed-Mat/OG
Used
Available

Figure 2. Trends in 9 breeding goshawk's habitat selection 5 habitat type categories, southern Cascades, California, 1988-1989. Differences in individual goshawk values of available from used frequencies are represented by "*". Values for each goshawk above the zero line indicate a trend towards avoidance and values for each goshawk below the zero line indicate a trend towards selection. Habitats are seedling/sapling/grass-forb, pole, open-small sawtimber/mature/old-growth, closed-small sawtimber, and closed-mature/old-growth and are defined in Table 1.



Value for ≥ 1 goshawk
Pooled value for all goshawks
Avail.(%) - Used(%)
0.4
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
-0.4
Seedling/ Sapling
Pole
Open-Sm. Saw/Mat/OG
Closed-Sm.Saw
Closed-Mat/OG

Table 3. Habitat selection analysis of 5 habitats for goshawks (pooled data, $n$ = 9)[a], southern Cascades, California, 1988 and 1989 breeding seasons.

| Habitat [b] | Frequency (%)[c] Available [d] | Used [e] | Confidence interval [f] | Result [g] |
|---|---|---|---|---|
| Seedling /sapling /grass-forb | 8 | 0 | 0.03 to 0.13 | - |
| Pole | 12 | 17 | (-0.14) to 0.04 | 0 |
| Open-small sawtimber /mature | 28 | 17 | 0.007 to 0.21 | - |
| Closed-small sawtimber | 42 | 46 | (-0.16) to 0.08 | 0 |
| Closed-mature /old-growth | 10 | 20 | (-0.22) to (-0.01) | + |

a Chi-squared = 25.02, 4 df, $P < 0.001$; The Chi-squared test of homogeneity was used to determine if available and used frequencies differed for each habitat category.

b Habitats described in Table 1.

c Percent of total frequency for each of available or used categories.

d Total sample size of available plots is 180.

e Total sample size of used plots is 180.

f Simultaneous confidence intervals used the Bonferroni $z$-statistic. Overall confidence level was 90%, individual confidence levels were 98%.

g Bonferroni simultaneous confidence intervals. A "0" value indicates the confidence interval includes zero, and no difference between available and used frequencies; a "-" value indicates the confidence interval does not include and is larger than zero, and indicates avoidance of this habitat; a "+" value indicates the confidence interval does not include and is less than zero, and indicates selection of this type.

Results of the analysis for individual goshawk selection of 5 habitats indicated no difference in use versus availability (Table 4). Trends for 7 of 9 individual goshawks suggest selection of the closed-mature/old-growth habitat ($\geq$ 40% average canopy closure) (Figure 2). One individual showed a slight trend toward avoidance, and this habitat was not found in the sample of random locations for 1 individual (Figure 2).

Analysis of individual goshawk selection trends of seedling/sapling/grass-forb habitats generally supported pooled data. This habitat seemed to be important to 6 goshawks and was not found in the sample of random locations for the other 3 goshawks (Figure 2).

No consistent trend of avoidance or selection for the open-small sawtimber/mature habitat (average canopy closure < 40%) was indicated by individual goshawk values (Figure 2). Six individuals seemed to have avoided this habitat, 2 individuals selected this habitat, and 1 goshawk had no difference between available and used proportions of this habitat.

Goshawks exhibited no consistent trend of selection or avoidance for the closed-small sawtimber habitat (Figure 2): 4 goshawk trends suggested

Table 4. Habitat selection analysis of 5 habitats for 9 goshawks, using Chi-squared test of homogeneity, southern Cascades, California, 1988 and 1989 breeding seasons.

| Goshawk | Chi-squared | df [a] | *P* |
|---|---|---|---|
| G01 | 4.87 | 4 | 0.301 |
| G03 | 3.78 | 2 | 0.151 |
| G04 | 9.07 | 4 | 0.059 |
| G05 | 3.86 | 3 | 0.277 |
| M02 | 4.56 | 4 | 0.336 |
| M04 | 6.77 | 4 | 0.149 |
| M05 | 3.84 | 4 | 0.427 |
| M08 | 15.60 | 4 | 0.004 |
| M09 | 2.79 | 2 | 0.248 |

a The degrees of freedom vary among goshawks because not all habitats were represented in the sample of available locations.

avoidance, 4 goshawk trends suggested selection, and 1 goshawk trend suggested no preference.

Goshawks exhibited no consistent trend of selection or avoidance of the pole habitat (Figure 2). Six individuals seemed to have selected this habitat, 2 individuals avoided this habitat and this habitat was not found in the sample of random locations for 1 goshawk (Figure 2).

Plot boundaries were bisected by changes in the forest structure 3.3 % of the used and 3.9 % of the total available locations. Changes in the forest structure were a clear-cut edge next to a closed-mature/old-growth stand, for instance.

Location error

Radio-tracking location error did not have a effect on the habitat selection results of 3 of the 5 total habitats analyzed. The effect of location error and the expected bias created by error did not result in type II errors for these 3 habitats.

Reproductive parameters

Attaching radio-tracking transmitters to breeding goshawks seemed to have no effect on reproductive success (Appendix 1 and 2). The percent of breeding pairs that were successful for adults with radios (_n_ = 8, 1988-1989) and without radios (_n_ = 10, 1987-1990) was 83% and 82% respectively (Appendix 2).

There was no difference in the average productivity (successful nests) of breeding goshawks between goshawks with and without transmitters attached (Kruskal-Wallis test, $P = 0.81$) (Appendix 2). The average productivity for successful nests where $\geq 1$ adult goshawk had a transmitter attached was 1.75 fledglings ($n = 8$), 1.80 fledglings for successful nests where no transmitters were attached ($n = 10$), and 1.78 fledglings for all successful nests ($n = 18$) (Appendix 1 and 2).

Average productivity for active nests was lower than for other studies (average of 1.38 - 1.40 fledged young per active nest, compared to a range of 1.7 - 2.1 for other studies; Appendix 1 and 2). A larger sample size is needed to estimate this parameter.

# DISCUSSION

## Scope and limitations

Goshawk locations were collected for only a portion of the goshawk breeding season (50 days of a 90-day post-hatching time period). In addition, locations collected could have been autocorrelated. Therefore approximation of data independence by collection of a representative, random sampling of locations throughout the breeding season was not realized.

The result of failure to collect independent locations is that the home range size is likely an underestimate (Swihart and Slade 1985). Most home range models assume independence of locations (White and Garrott 1990: 147). Failure to meet assumptions of data independence also can result in difficultly making inference to the research population. The results of the habitat selection and home range analyses for this study should be applied to this and other populations cautiously.

It is unlikely that any bias created by the habitat plots bisected by a habitat edge had an effect on my results. The small proportion of bisected plots (3.3% of used and 3.9% of available plots) suggests that misclassification of a goshawk's use of seedling/sapling/grass-forb to the use of any other habitat would not have affected habitat selection results.

Because most of the data analyzed is from 1 member of separate pairs (7 of 9 pairs) failure to meet the assumption of independence of goshawks would not likely have an effect on my results.

Home range size

White and Garrott (1990: 178) discussed the subjective nature of home range estimation and suggested that studies be more precisely designed to use other more informative, objective techniques to investigate a species' use of habitat, rather than rely on a estimator which is poorly understood or defined. Different home range methods give very different, non-comparable results (Appendix 6). In addition, the MCP home range method can include areas of non-use in the area estimate. In the case of my study, the MCP method assisted in defining an area within which habitat selection was investigated, and this can suggest an area within which management of habitat for breeding goshawks is considered. I did not investigate the home range using other methods because of small sample sizes.

The area used by a pair of breeding goshawks and young is likely to be larger than the home range of 1 adult, and smaller than the sum of the home ranges of both adults. I estimated that an area used by a pair of goshawks in my study area is approximately 4,765 ha, by summing the average values for males and females, and subtracting the estimated pair home range overlap of 38% of the average female home range.

Densities of breeding goshawks have been estimated for my study area at 1.9 pairs per 100 $km^2$ (Appendix 7) or 1 pair of goshawks per 5,263 ha, assuming no overlap in home range use between adjacent pairs.

It is likely that the density estimate for my study area is an underestimate, based on the fact that the non-systematic surveys used to locate nests did not detect all nesting goshawks each year. It also is likely that the average home range values for male and female goshawks are underestimates, based on the small sample size of locations collected per goshawk and possible autocorrelation of locations. Larger values of both parameters would suggest overlap between home ranges of adjacent pairs of goshawks. Overlap between adjacent goshawks was observed for several adjacent pairs during field data collection.

Other research estimates of goshawk home ranges in the United States using radio-tracking averaged between 900 and 1,979 ha (Appendix 6). The average home range value in my study (3,100 ha) is higher than other goshawk home range estimates in North America. The minimum convex polygon method encompasses areas of non-use, and estimates generated in my study using this method would be expected to be larger than estimates which define areas of high use and minimize the inclusion of areas of non-use, such as the harmonic mean method (Dixon and Chapman 1980) used by Kennedy (1990) and the adaptive kernel method (Worton 1989) used by Hargis et al. (In press).

Sexually size-dimorphic raptor species such as the goshawk are theorized to partition prey resources by size (Newton 1979: 24). Snyder and Wiley (1976) suggested that it could be energetically cost-efficient for females to hunt larger prey species closer to the nest. This suggests that female goshawks would have smaller home ranges than males during the breeding season. Kennedy (1990) and Hargis et al. (In press) concluded that female goshawks had smaller home ranges than male goshawks during the breeding season. My results did not agree with others, but differences in location sample size and analysis could explain these differences.

Habitat selection

Goshawks used 4 of 5 habitats within 9 home ranges which supports the observation that goshawks use many forest types and habitat conditions for foraging and resting (Kenward and Widen 1989, Reynolds et al. 1991).

Similarly, Hargis et al. (In press) concluded that goshawks were selecting home ranges with high vegetative diversity and mature forest edge, indicating that goshawks were selecting sites with diverse habitat conditions.

Goshawks selected the closed-mature/old-growth habitat ($\geq$ 40% average canopy closure) (Figure 1) and trends generally agreed with this result (Figure 2). Hargis et al. (In press) in eastern California, Fischer and Murphy (1986) in Utah, and Widen (1989) in Sweden also found non-random use of habitat by goshawks.

In an eastern California study, goshawks selected stands with structural attributes more typical of mature and old-growth forest than what was available within the study area (Hargis et al., In press). Basal area, and number of large trees per acre were greater in nesting and foraging locations than found randomly in the study area (Hargis et al., In press). Selection or avoidance of old-growth forest was not indicated and selection of other available habitats within the study area was not investigated (Hargis et al., In press).

In Sweden, goshawks used stands $\geq$ 60 years more frequently than expected by availability (Widen 1989). Most successful foraging attempts were documented in stands of mature forest, although prey densities were not believed to be higher in these stands (Widen 1989).

A radio-tracking study of goshawks in Utah indicated that 1 individual selected mature white fir / Douglas-fir (Pseudotsuga menziesii) forests, which was composed of larger size (dbh) trees and more open structure than was available in other habitats (Fischer and Murphy 1986).

Avoidance of open, seral-stage habitats by goshawks is supported by Fischer and Murphy (1986). They concluded that 2 goshawks avoided open, montane slopes in Utah. In a Swedish study, clearcuts, agricultural land, and wetland habitats were used in proportion to their availability by goshawks (Widen 1989).

Analysis of goshawk selection of the open-small sawtimber/mature habitat was inconclusive; individual trend data does not support the results from pooled data. It is possible that the open structure of the stand, or factors not studied, such as prey abundance, could have contributed to avoidance of this habitat by some goshawks but not others.

Widen (1989) and Fischer and Murphy (1986) concluded that goshawks were avoiding dense, early hardwood forest because the dense structure provided difficulties for goshawks in flight.

The closed-small sawtimber habitat was not selected by goshawks. This habitat provides both a closed canopy (average $\geq$ 40%), and trees of adequate size and spacing to create a suitable habitat structure for goshawk flight, cover and perching. These results are understandable if one considers the concept that the determination of selection of a habitat requires that a resource be limited (Johnson 1980). This was the most commonly available and commonly used habitat for all goshawks pooled, and occurred within the home range of all individuals. It is possible that goshawks selected home ranges with adequate amounts of this habitat (second order selection; Johnson 1980). Further research is needed to investigate this question.

Possible reasons for lack of selection or avoidance of both the pole or the closed-small sawtimber habitats includes type II error. Type II error could have resulted because of either a small sample size of locations for all goshawks in this study (Alldredge and Ratti 1986, Thomas and Taylor 1990), or the bias created by error in identification of habitats (Nams 1989).

If most locations represented foraging locations, then selection of foraging habitat by goshawks may be a compromise between habitats that provide structures conducive to hunting and habitats which provide high prey densities (Widen 1989). In a Swedish study, most successful foraging attempts documented were within patches of mature forest, although prey densities were not believed to be higher in these stands (Widen 1989). Thus it was the structure of this habitat which was believed to have affected goshawk selection of this habitat for foraging. Reynolds and Meslow (1984) hypothesized that goshawk use of the lower canopy region in Central Oregon forests corresponded to the ground-shrub and shrub-canopy zones where the goshawk's most common prey species were found. Hunting behaviors of goshawks has been described as short-stay perched-hunting (Kenward 1982) which might result in greater hunting success in habitats which provide perch sites and open understory structure for observation of prey, but enough overstory cover for the goshawk to remain undetected during foraging movements (Widen 1989). European goshawks rely on different foraging techniques in different habitats (Widen 1984).

Closed-mature/old-growth stands also could provide thermal and/or protective cover. Seedling/sapling/grass-forb habitats avoided by goshawks might provide sub-optimal structure for goshawk resting because these habitats would not provide thermal or protective cover.

The seedling/sapling/grass-forb habitats may have provided sub-optimal habitat structure for goshawk foraging. A sparse overstory could reduce the availability of perches for hunting or could leave a hunting goshawk more exposed and thus reduce foraging success in open habitats.

Edges between open and closed-canopied habitats could provide a variety of prey species and foraging opportunities for goshawks. The conclusion that goshawks were avoiding large openings such as clearcuts and meadows should not suggest that goshawks in this study area were not using edges of forest and openings for foraging. It is possible that early-successional forest and unforested patches may provide an abundance of certain prey species, and the edge of forest-openings may be areas of high prey availability. Kenward (1982) observed that goshawks foraging attempts occurred primarily within 200 m of a forest edge. He suggested that goshawk home ranges varied with the availability of prey along this habitat rather than with the amount of edge habitat. He concluded that perches and cover were necessary for most successful attacks (Kenward 1982).

Location error

The effect of location error and the expected bias created by location error (Nams 1989) did not result in type II errors for 3 of 5 habitats. Had I obtained a larger sample size of locations or had I based my analysis on locations of known confidence, then I might have detected selection or avoidance of additional habitats.

Landscape patterns and goshawk populations

Questions regarding the effect of timber harvest on northern goshawks often can be posed in terms of whether this species requires large, contiguous blocks of mature and old-growth forest. Kenward (1982) concluded that goshawks probably have benefitted from fragmentation of previously continuous forests in Europe. In the Kaibab Plateau region of Arizona, Crocker-Bedford (1990) found that goshawk nest occupancy and reproductive success was lower in areas where single-tree selection selection regeneration systems were used in comparison with areas with little to no prior harvest.

The question of whether goshawks were more abundant prior to historic timber management practices is not possible to answer for my study area. A description of the home range size and habitat use of goshawks in a managed landscape is possible and was the focus of my research.

The reproductive success and productivity of successful and active nests for my study area are lower than for other study areas. Because this is calculated from a small data set, data collected over a short duration and because reproductive data alone are insufficient to address the question of whether a population is stable or declining, more information is needed before I can assess whether the results of my study apply to a stable population of goshawks.

# CONCLUSIONS

My results generally agree with other goshawk habitat use and home range size studies: 1) goshawks use large home ranges ($\bar{x}$ = 3,100 ha), 2) goshawks use a variety of habitats categorized by structural characteristics, 3) breeding goshawks seem to select mature and old-growth stands with closed-canopy ($\geq$ 40%) for activities such as nesting, resting and foraging.

Estimates of the area used by a breeding pair of goshawks for my study area based on male and female home ranges and pair overlap is 4,765 ha and is comparable to an estimate based on breeding densities for my study area of 5,263 ha.

This study describes the use of 5 habitats within 9 goshawk home ranges. Defining the precise habitat requirements of a species may not be possible, yet the degree of habitat selection that populations exhibit over geographic range and time may reflect habitat requirements for wildlife species (Ruggeiro et al. 1988). The results of my research can be useful in this context.

Analysis of habitat selection at various spatial scales is important to fully understand a species' habitat use (Allen and Star 1982, Johnson 1980, Woodbridge 1991). Analysis at the micro-habitat scale can give an understanding of what attributes of a habitat a goshawk is selecting or the ultimate selection factor for the individual (Hutto 1985), such as foraging, thermal or protective cover. The stand level analysis provides information on patch use within home ranges, such as my research. Analysis at the landscape scale can help answer questions on how much of each available habitat and in what distribution comprises the range of acceptable landscapes used by a breeding pair of goshawks. The distribution and abundance of breeding goshawks gives information on regional variation in habitat selection and breeding densities, and suggests the potential for movements of individuals between populations.

Stands of the closed-mature/old-growth habitats were selected by breeding goshawks. A conservative assumption, until more information is available, is that this habitat is important to maintaining goshawk populations within my study area.

Early-successional forests or unforested habitats (seedling/sapling/grass-forb) seemed to be less important habitats for breeding goshawks in my study area. Small openings and edges between forested and early-successional stage patches could provide important foraging opportunities for goshawks, although I did not investigate foraging behavior. A conservative recommendation at this time would be to minimize the acreage of this habitat within goshawk home ranges until more information is available.

Although the closed-small sawtimber habitat was not selected or avoided by goshawks, it was estimated as the most commonly used habitat (46% of used samples) within goshawk home ranges. This habitat was likely an important component of goshawk home ranges.

# MANAGEMENT IMPLICATIONS

Current management of goshawk habitat in the U.S. Forest Service in Region 5 could be inadequate to maintain nesting territories for this large, forest-inhabiting raptor across managed landscapes. The majority of the area used by a breeding pair of goshawks and their young is not considered during land management or project planning on National Forest land. An important component of the goshawk breeding home range in this study, closed-canopied mature and old-growth forests, is often managed under current guidelines without consideration of goshawk habitat relationships outside of the nest stand.

Management recommendations which follow are not meant to be extrapolated beyond the limitations of my study, but in the absence of other information, these data can be used in developing interim recommendations and can help focus future research efforts.

1) The area considered for management of habitat for breeding goshawks on public lands within the range of the northern goshawk should be expanded to include an area used by a pair of goshawks. A recommended size for a management area is a minimum of 4,765 contiguous hectares (11,774 acres). This recommendation is best applied in regions with landscape patterns, and habitat stages (Verner and Boss 1980) similar to my study area.

Overlap between adjacent goshawk management areas can be based on the inter-nest distances documented for each specific case, or on adequate estimates of goshawk breeding densities for the region where management is applied.

The minimum size recommendation for goshawk management areas is based on the sum of the average 100% MCP male (2,425 ha) and female (3,774 ha) (Table 2) home ranges, and subtracting 38% of the female home range to allow for overlap between members of a pair.

Regions within the range of the northern goshawk, with different landscape patterns, plant communities and habitats than those found in this study area, may consider promoting cooperative breeding goshawk density studies to evaluate the densities of breeding goshawks and the habitats surrounding nests.

2) Within each goshawk management area habitats should be managed for a variety of goshawk activities (foraging, resting, nesting and raising young) for a pair of goshawks.

A) I recommend that at least 20% of the management area (>953 ha) be in the closed-mature/ old-growth habitat (average dbh $\geq$ 52 cm or $\geq$ 21 in.; average canopy closure $\geq$ 40%), based on the proportion of use of this habitat by goshawks in my study.

Reynolds et al. (1991) recommended managing a total of 40% of the post-fledgling area and foraging area (approximately 5,000 acres around the nest) in habitats (VSS 5 & 6) which correspond approximately to the closed-mature/old-growth habitat recommended here.

B) I recommend that a minimum of 40% of the management area (> 1,906 ha) should be managed in the closed-small sawtimber habitat (average dbh 26-51 cm, or 11-21 in.; $\geq$ 40% average canopy closure), based on the average proportion of use of this habitat by breeding goshawks in my study.

It is likely that the closed-small sawtimber habitat provides suitable resting and foraging habitat for goshawks, even though this habitat was not selected by goshawks in this study. This habitat was the most common habitat found randomly within home ranges was the most common habitat used by goshawks and is a habitat that is often used for nesting (Hall 1984, Moore and Henny 1983, Reynolds et al. 1982, Saunders 1982).

Reynolds et al. (1991) recommended managing approximately 20% of the post-fledgling area and foraging area in habitat (VSS 4) which corresponds approximately to the closed-small sawtimber habitat.

C) I recommend that < 10% of the management area (< 476 ha) should be in the seedling/sapling/grass-forb habitats or unforested condition at any time. The results of this study indicate that this habitat was unused by goshawks, but the average proportion of this habitat within goshawk home ranges was 8% (table 3).

Reynolds et al. (1991) recommended managing approximately 20% of the post-fledgling area and foraging area in habitats (VSS 1 & 2) which corresponds to the seedling/sapling/grass-forb habitat recommended here.

The above management recommendations are based on results of my study and modeled after the southwestern goshawk management recommendations (Reynolds et al. 1991). The interim strategy recommended for the Southwestern Region of the U.S. Forest Service (Reynolds et al. 1991) is dependent on breeding surveys to locate actively breeding goshawks before goshawk management areas are identified.

Alternatively, a conservation area approach (Thomas et al. 1990) can be implemented, which would designate large blocks of suitable habitat for multiple pairs of breeding goshawks, and provide for movement of goshawk adult and juveniles between blocks. This type of strategy is not as dependent on funding and implementation of breeding surveys.

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# APPENDICES

Appendix 1. Discussion of reproductive parameter values for goshawks, southern Cascades, California, 1987 to 1990.

Yearly numbers of breeding goshawks located during U.S. Forest Service wildlife surveys seemed to have been relatively constant over the last 8 years (1982-1990; unpublished data).

Reproductive success of goshawks in my study area (82-83% successful nests of all active nests) is lower than estimates for northern California (84%; Woodbridge and Detrich) (93%; Bloom et al. 1986) and for southeastern Oregon (90%; Reynolds and Wight 1978) (Appendix 2).

Productivity of successful nests (pairs that successfully fledge young) between 1987 and 1990 for my study area (average of 1.75-1.80 fledged young per successful nest) is supported by comparable values of a second study in the southern Cascades (1.88) (Woodbridge and Detrich, In press) (Appendix 2). The productivity of successful pairs for my study is lower than that documented in a southeastern Oregon study (2.3) (Reynolds and Wight 1978).

Productivity of active nests (pairs that laid eggs) is considerably lower for my study area (average of 1.38-1.40 fledged young per active nest) than for several other study areas (1.7-2.1) (Appendix 2). During the period that productivity was measured 3 goshawk nests failed, probably caused by late-spring storms. Because approximately 25% of the total sample of nests failed caused by an unusual weather over a 4 year period the estimate of productivity for active nests is probably deflated. In addition, 2 nests failed while one adult was wearing a radio-transmitter. A larger sample size is needed to estimate productivity.

In summary, the reproductive success and productivity of successful and active nests are lower than documented for other study areas. Although data suggested that reproduction of goshawks is lower between 1987-1990 than for other study areas, more information is needed to determine if this population is stable or declining over time.

The reproductive data presented here is based on the breeding segment of the population. But the most frequent cause of depressed productivity of raptor populations is failure of territorial pairs to lay eggs (Postupalsky 1974). Steenhof (1987) suggests estimating the percent of the population that is territorial but not actively breeding to avoid this problem. This is difficult to do with forest inhabiting birds such as the goshawk. Other information such as recruitment, and survival are necessary to assess the stability of populations (Soule 1987: 13).

Appendix 2. Productivity and reproductive success for breeding goshawks on the McCloud (1987-1990) and Goosenest Ranger Districts (1988), southern Cascades, California, and for other studies.

| Research cited | Productivity [a] (n nests) Successful nests [b] | Active nests [b] | Reproductive success (%) (n nests) [c] |
|---|---|---|---|
| This study [d]; No transmitter attached. | 1.80 (10) | 1.38 (13) | 82 (18) |
| This study [d]; Radio-transmitter attached. | 1.75 (8) | 1.40 (10) | 83 (12) |
| McGowan (1975) | | 2.0 (33) | |
| Reynolds and Wight (1978) | 2.3 (25) | 1.7 (48) | 90 (52) |
| Bloom et al. (1986) | | 1.72 (50) | 93 (65) |
| Crocker-Bedford (1990) | | 2.1 (19) | |
| Woodbridge and Detrich (In press) | 1.88 (20) | | 84 (89) |

a Productivity is defined as the average number of young fledged per territorial pair. For this study, productivity is defined as the average number of young fledged per active/successful breeding pairs. It is difficult to determine that a pair of goshawks is defending a territory but not breeding, because goshawk territories are often located when pairs defend nests.

b Successful nests are nests where > 1 young has fledged. Active nests are nests where > egg was laid.

c Percent of breeding pairs that successfully fledge young.

d Data from goshawks with and without radio-transmitter attached (1987-1990). No difference between productivity (successful nests) of goshawks with and without radio-transmitter attached (Kruskal-Wallis test, $P = 0.81$

Appendix 3. Ten goshawks fitted with radio-transmitters during breeding season of 1988, southern Cascades, California. Corresponding sex, paired status, length of time goshawk was tracked (days), sample size of radio-tracking locations, and whether data for an individual was used in home range and habitat use analyses.

| Goshawk | Sex [a] | Pairs [b] | Tracking length (days) | Location sample [c] | Analyzed [d] |
|---|---|---|---|---|---|
| G01 | F | | 44 | 27 | Y |
| G02 | M | | 45 | 36 | Y |
| M02 | F | | 74 | 31 | Y |
| M03 | F | | | 0 | |
| M01 | F | | | 11 | |
| G04 | M | | 56 | 31 | Y |
| G03 | F | | 48 | 32 | Y |
| M04 | F | A | 63 | 43 | Y |
| M05 | M | A | 57 | 41 | Y |
| G05 | M | | 51 | 34 | Y |

a F = female, M = male.

b Goshawks with same letter were a mated pair.

c Number of goshawk locations collected using radio-tracking.

d Goshawks for which data was analyzed in this study are indicated by Y. Goshawks excluded from analysis were those with < 20 locations collected.

Appendix 4. Six goshawks fitted with radio-transmitters during breeding season of 1989, southern Cascades, California. Corresponding sex, paired status, length of time goshawk was tracked (days), sample size of radio-tracking locations, and whether data for an individual was used in home range and habitat use analyses.

| Goshawk | Sex [a] | Pairs [b] | Tracking length (days) | Location sample size [c] | Analyzed [d] |
|---|---|---|---|---|---|
| M06 | M | | | 0 | |
| M07 | F | B | | 3 | |
| M08 | M | B | 29 | 29 | Y |
| M09 | F | | 51 | 28 | Y |
| M10 | F | C | | 3 | |
| M11 | M | C | | 5 | |

a F = female, M = male.

b Goshawks with same letter were a mated pair.

c Number of goshawk locations collected using radio-tracking.

d Goshawks for which data was analyzed in this study are indicated by Y. Goshawks excluded from analysis were those with < 20 locations collected.

Appendix 5. Forest structural stages used to classify vegetation in habitat plots (used and available) within goshawk breeding home ranges, southern Cascades, California, 1988 and 1989 [a].

| Code | Size (dbh) [b] | Forest development stages | Code | Canopy closure (%) [c] |
|---|---|---|---|---|
| 1 | 0-11 cm | Seedling, Sapling, Grass-forb | S | 10-19 % |
| 2 | 12-25 cm | Pole | P | 20-39 % |
| 3 | 26-51 cm | Small sawtimber | N | 39-69 % |
| 4 | ≥ 52 cm | Mature | G | ≥ 70 % |
| 5 | ≥ 52 cm | Old-Growth [d e] | | |

a These categories are based on the USDA Forest Service Region 5 forest structural stages (USDA Forest Service 1987).
b dbh = diameter at breast height (cm).
c Average canopy closure is measured from shrub height (approximately 2 m) and higher. This measure is averaged over the plot sampled, in this case a 30-meter radius plot (see methods section).
d Old-growth is categorized as stands with additional vertical structure and higher abundance of down and standing dead wood than found in mature forest stands.
e Old-growth forest is included in the description of the oldest habitat but is not found within most of my study area.

Appendix 6. Estimates of the breeding home range size for the goshawk in North America using various methods (modified from Reynolds 1983).

| Size (ha) | Location | Method | Source |
|---|---|---|---|
| 3,100 | Northern California | Radio-tracking; Minimum Convex Polygon (100%) | This study. |
| 1,979 | Minnesota | Foraging radius | Eng and Gullion (1962) |
| 2,463 | Eastern Oregon | Distance between active nests | Reynolds (1979) |
| 1,146 | New Mexico | Radio-tracking; Harmonic Mean (95%) | Kennedy (1990) |
| 900 | Eastern California | Radio-tracking; Adaptive Kernel (95%) | Hargis et al. (In press). |

Appendix 7. Estimates of goshawk breeding densities in North America.

| Density (pairs/ 100 $km^2$) | Location | Method | Source |
|---|---|---|---|
| 1.9 | Northern California | Inter-nest distances; Incomplete surveys. | This study and unpublished data (1988-1990) |
| 4.3 | Eastern Oregon | Complete survey of landscape. | Reynolds and Wight (1978) |
| 3.2 | California | Inter-nest distances; Incomplete surveys. | Bloom et al. (1986) |
| 6.3 | Eastern Oregon | Complete survey of landscapes. | DeStephano and Meslow (1992) |
| 11.0 | Arizona | Survey of landscape. | Crocker-Bedford and Chaney (1988) |